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Agricultural Memorandum No. 799

Soil 4-inch Temperatures in a Heated Glasshouse

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Summary

Observations of 4 in. soil temperatures at several positions in ground beds, troughs and pots in a heated greenhouse growing tomatoes show that although there is little difference in average temperature from site to site, the diurnal range in troughs is about $1\frac{1}{2}$ times, and in pots $3\frac{1}{2}$ times that in open soil.

The effect of watering on diurnal range is relatively small but appears to be greater with hose watering than spray-line watering. Depressions of soil temperature over short periods of time could be more significant in the possible effect on plant growth, but more information is required before a conclusion can be reached.

1. Introduction

During 1951 a series of observations of meteorological elements was made by Mr S A Searle in commercial glasshouses belonging to Messrs Frampton of Leythorne, Chichester. The building considered was a continuous block of four N.S.houses in which tomatoes were grown. In the most easterly house (No 9) the crop was grown in raised beds in concrete troughs and in pots; in the other three (Nos 10, 11 and 12) the crop was grown in ground beds in the usual way. Among the instruments used were seven 4 in. bent stem soil thermometers (all tested and certified); these were sited as follows:-

Thermometer A No 12 house (the most westerly) 27 ft from north end, 15 ft. from west end.

C No 12 house centre of house 15 ft from west end.
F " " " 18 ft from south end 15 ft from west end.
S " " " centre of house 1 ft from west end.
H No 11 house centre of house 45 ft from west end.
M No 9 house in soil in a concrete trough centre of house.
N " " " in soil in a 12 in. pot centre of house.

Between mid February and mid July readings were taken several times daily, but other duties prevented fixed-hour readings. Sufficient observations were made during the day to interpolate hourly values between about 0700 and 1800 in spring and 0600 and 2200 in summer. The results were analysed for each period of 10 (or 11) days and also for the sunny and dull days in each month.

2. Temperatures at 0900h.

The mean 0900 temperatures over 10 day periods are given in Table 1 together with the corresponding outdoor values. The soil at 4 in in the glasshouse is some 20°F warmer at this time of day than that outside in February, but by June the difference is practically nil. The differences between the averages for thermometers A, C, F and H are small but the values for the soil in troughs (M) and pots (N) are, in general, lower than those for the ground beds until mid June. The soil near the west wall of the houses had very low 0900 temperatures in the early months; equality with the rest of the house was not reached until mid May, and after this date it experienced warmer temperatures than elsewhere.

3. Average Mean Daily Temperature

If we find the mean daily temperature by the mean of 24 hourly values at positions H, M, N and S and compare it with the mid-temperature we find that the two figures agree exactly for H, M and S and there is a slight discrepancy in the case of N which decreases as the days get longer. For ease of comparison the average mid-temperatures have been listed in Table 2, together with the mean of the 24 hourly values for N (N').

From these figures the first comparison we can make is along the length of the house, namely A, C and F. The soil in the north end of the house is colder than that in the south end throughout the period except during the first ten days in June, before which uneven picking and defoliation of the crop may have resulted in extra shade at F. The average difference throughout the period is 0.95°F. In the comparison of C and A we find that the soil in the centre of the house is slightly warmer than the soil in the north end in March and April, but later the north end is warmer. The average difference throughout is negligible.

The comparison across the houses is shown by the differences H-S and H-C. As was noticed in Table 1, the soil at S was very cool in the early months, that in the inner house being 4 to 6°F warmer until the end of April when the difference fell to 3°. After June the soil near the outside west wall was warmer. Soil at H was warmer than soil at C for most of the period. Although in July the outer house became warmer, this was probably due to the lower trusses being stripped during June and more sunlight reachimg the parts of the houses away from the centre of the inner pair.

The comparison between the mean temperatures in the ground beds (H) and in troughs (M) and pots (N') shows that H is warmer than M and N' by about 1-3 degrees over most of the period, but after mid-June when much foliage and fruit has been removed this difference is reversed.

4. Average Diurnal Range

Table 3 shows the average diurnal range at each site over the 10-day periods, together with the corresponding averages of sunshine and plant heights.

Comparison along the length of the house (A-C-F) shows that in general the diurnal range at the north end is 9/10 that at the south end (A/F); in the middle the ratio is 8/10 (C/F). Thus, the range is greatest at the ends of the house and least in the middle. The only times the south end does not have a larger range than elsewhere are at the end of February and the latter half of May, and as we have stated in para 3, uneven defoliation and consequent uneven shading probably affected the soil around F about this time. During the last 30 days of observations when the plants were stripped to about half their height, the ratios A/F and C/F average 0.8 and 0.66 respectively.

Comparison across the house (H-C-S) shows that until the end of April the variation at C is less than that at H, but afterwards there is little difference. At S the variation is about half that at H in the early stages but after the middle of May the variation is greater at the side.

The diurnal range in the troughs is between 1½ and 2 times that in the level soil of the ground beds; in pots the ratio is at times as high as 4 and on the average is 3.35.

5. Average Diurnal Range on Sunny and Dull Days

Sunny days were defined as those with 6 hours or more sun in February, 7 in March, 8 in April, 9 in May and 10 in June and July. Dull days were those with less than 1 hour's sunshine. The average ranges for days of both types in each month are shown in Table 4, together with the corresponding mean sunshine hours.

We can assemble the monthly values over three main periods:-

February,	initial growth,	plant height 1 ft or less.
March, April,	full leaf,	plant height increased from 1 ft - 6 ft
May, June, July,	picking,	lower trusses and leaves successively removed,

and the following ratios with respect to H are obtained:-

	A/H	C/H	F/H	M/H	N/H	S/H
Initial growth	0.89	0.68	0.96	1.6	3.3	0.53
Full Leaf	0.85	0.83	1.00	1.85	3.7	0.61
Picking	1.08	0.95	1.27	1.6	3.3	1.06

In the first and third periods when there is least shading from leaves, the ratios M/H and N/H show that the diurnal range is about $1\frac{1}{2}$ times greater in troughs than in ground beds and about $3\frac{1}{2}$ times greater in pots. In the second period, when there was maximum shading of the soil, the ratios are even greater, probably because in troughs and pots the lowest leaves and trusses are further away from the floor of the house, with a greater fraction of the radiation striking the sides of the troughs and pots.

With respect to the ground beds, the centre of the houses (H) has the greater range in the first period when external conditions are cold; in the third period the sides of the house (especially at F to the south) have larger ranges, as there is less shading by the higher remaining leaves and trusses.

6. Diurnal Range and Sunshine Hours

In a glasshouse, where wind is almost absent and soil moisture conditions are kept uniformly high, it is attractive to attempt a linear relationship between diurnal range and sunshine hours. A series of regression equations have been calculated for H and are given in Table 5.

At first when the plants are small the regression coefficient increases with increasing power of the sun (February to early March). Thereafter the increasing shade provided by the growing plants more than compensates for the increased radiation intensity and the coefficient decreases until the picking and stripping of the lower leaves and trusses in late May and early June again causes an increase in the coefficient.

7. Effect of Watering

(a) The water (from a well) applied (at A, C, F and S by overhead spray-lines, and at H by hose) was not warmed and was colder than the air and soil. The distribution of the W dots in Figures 6, 7 and 8 does not suggest any undue depression of the diurnal range.

If we compare the diurnal range estimated from the regression equations and the actual range on days when watering occurred we get the following results:-

Hose watering at H	Range less than expected	19 days
	" more than expected	11 days
	Average decrease from estimate	0.23°F.
Spray watering at C	Range less than expected	15 days
	" more than expected	10 days
	Average decrease from estimate	0.08°F

The net effect of watering on diurnal range thus appears to be small, but there is some slight evidence to the effect that the depression effect is less in spray-line watering. It must however be remembered that our initial regression equations have been calculated from data which included the watering days.

If we find similar equations for the separate classes we find for the April to July period:-

Hose watering (H)	Watering days	Diurnal range is $1.5^{\circ} + 0.16h$
	Non-watering days	$2.2^{\circ} + 0.17h$
Spray watering (C)	Watering days	$1.1^{\circ} + 0.22h$
	Non-watering days	$1.5^{\circ} + 0.20h$

This suggests that on dull days there is a depression of 0.7° in the range in hose watered beds and 0.4° in spray-line watered beds. On sunny days the depression is 0.8° and 0.2° respectively. More precise experiments with adjacent beds watered and unwatered were not possible under commercial conditions, but the present indications are that the effect on the diurnal range at 4 inches is not large.

The exact temperature of the applied water was not measured, but from observations of soil temperatures at the depth of the well, it is possible that it could have been as much as 15-20°F colder than the 0900h 4 in. soil temperature in April and May and 7-11°F colder in June and July. Nevertheless greater depressions of diurnal range were not conspicuous in the earlier months which suggests the presence of the water in the soil is of more significance in affecting the diurnal range than the actual temperature of the applied water.

(b) Although the effect on the diurnal range is not large, it is possible that cold water may cause a drop in 4-inch soil temperature over a shorter period. Again, commercial conditions precluded the detailed examination of temperature minute by minute, but over periods of 1-3 hours, day time depressions in 4-inch temperature after watering were recorded as follows:-

H (hose)	30	Watering-days.	Depression	observed	on	11	occasions,	maximum	1.9°F.
A (spray)	25	"	"	"	"	3	"	"	0.5°F.
C (")	25	"	"	"	"	8	"	"	0.8°F.
F (")	25	"	"	"	"	5	"	"	1.2°F.
S (")	25	"	"	"	"	4	"	"	0.8°F.

Under hose watering, depressions were observed on 37% of the occasions, with an average depression of 0.56°F.; under sprays we have an average of 20% of the occasions, and average depression of 0.39°F. Larger and more frequent depressions might have occurred but, as explained previously, conditions prevented their

observation. Again there is some evidence for the smaller depression effect of spray-line irrigation.

The pots were watered daily, and in 101 days depressions were observed on 29 occasions, but with the large diurnal ranges which normally occurred it was very difficult to be sure whether some of these apparent depressions were due to 5° errors in reading. The average depression was 2.2°, but with the rapid intake of heat through the sides of the pots, the large falls in temperature soon disappeared. It is thought that no firm deductions can be made in this field without more precise observations.

TABLE 1

Average 0900h Temperatures

		A	C	F	H	M	N	S	Outside
Feb	10-19	55.9	-	56.9	56.1	54.4	55.2	53.3	39.6
	20-28	57.4	-	58.4	59.1	56.7	56.8	54.1	38.5
Mar	1-10	58.0	58.3	59.2	60.1	56.8	57.7	55.1	37.9
	11-21	59.8	59.8	60.0	61.0	58.3	59.4	56.6	42.4
	22-31	61.5	61.9	62.1	62.9	59.9	61.4	57.6	41.3
Apr	1-10	63.3	63.7	63.5	63.9	60.8	61.6	58.7	43.7
	11-20	63.6	64.5	65.0	65.3	62.7	64.3	59.9	44.9
	21-30	64.0	64.2	65.7	66.1	62.9	64.7	63.1	47.8
May	1-10	65.0	64.8	65.8	66.6	63.3	64.6	63.7	50.0
	11-21	63.4	62.9	64.5	65.7	64.1	65.1	63.0	52.4
	22-31	64.1	63.8	65.2	65.7	64.4	64.8	65.0	55.9
June	1-10	66.1	65.1	65.3	66.9	64.7	65.1	66.7	58.7
	11-20	65.5	65.3	66.6	66.7	66.7	67.7	67.7	61.2
	21-30	64.0	63.8	65.0	64.5	64.3	64.8	64.0	62.0
July	1-10	66.0	65.6	67.2	65.8	66.2	66.8	67.0	62.9
	11-20	64.7	64.7	65.6	64.5	-	-	65.1	63.9

TABLE 2

Average mid-temperature

		A	C	F	H	M	N	S	Mean 24hr N^1
Feb	10-19	57.0	-	58.1	57.5	56.6	58.6	53.9	57.8
	20-28	59.3	-	60.0	59.9	59.6	61.8	55.0	60.3
Mar	1-10	59.2	59.4	60.4	61.3	59.1	61.2	55.8	59.9
	11-21	61-1	61-1	61.5	62.5	61.1	63.6	57.3	61.7
	22-31	62.5	62.8	63.1	64.0	62.1	63.0	58.1	62.1
Apr	1-10	64.1	64.6	64.6	65.3	63.1	64.6	59.4	63.1
	11-20	64.5	65.4	65.8	66.5	65.3	66.6	60.4	65.3
	21-30	64.7	65.2	66.6	66.8	64.7	65.7	63.7	64.4
May	1-10	65.8	65.6	66.6	67.4	65.3	65.4	64.3	64.5
	11-21	64.4	63.8	65.2	66.3	65.7	65.7	63.8	65.2
	22-31	65.0	64.6	66.1	66.3	65.8	65.3	65.8	64.5
June	1-10	67.5	66.6	67.1	68.0	66.5	65.5	68.4	64.8
	11-20	67.2	66.8	68.5	67.9	68.4	67.8	69.4	67.3
	21-30	65.9	65.3	67.1	66.1	66.4	66.1	65.9	66.0
July	1-10	68.2	67.8	69.9	67.6	69.0	68.8	69.3	68.5
	11-20	66.7	66.5	67.8	65.9	-	-	67.1	-

TABLE 3

Average Diurnal Range

		A	C	F	H	M	N	S	Mean Sun Hrs	Height of plants
Feb	10-19	2.3	-	2.4	2.9	4.5	9.2	1.2	2.8	8 ins
	20-28	3.8	-	3.4	3.6	5.9	10.9	1.8	4.3	12 ins
Mar	1-10	2.5	2.3	2.6	2.4	4.5	10.0	1.5	2.5	18 ins
	11-21	2.9	2.8	3.2	3.3	5.8	11.6	1.7	3.9	24 ins
	22-31	2.0	1.9	2.3	2.5	4.6	8.0	1.2	3.6	3 ft
Apr	1-10	1.9	1.9	2.5	3.1	4.7	10.4	1.8	4.6	4 ft
	11-20	2.4	2.3	2.5	3.2	6.0	10.3	1.9	6.8	5 ft
	21-30	1.9	2.2	2.7	2.2	4.7	9.8	1.6	9.2	6 ft
May	1-10	2.3	2.1	2.7	2.3	4.8	9.0	1.7	4.9	8 ft
	11-21	2.2	2.0	1.9	2.1	4.6	6.8	2.1	7.3	8 ft 6 ins
	22-31	2.4	2.0	2.4	1.9	3.7	7.9	2.1	6.4	"
June	1-10	3.9	3.4	5.2	3.4	6.0	10.3	3.9	12.5	"
	11-20	3.8	3.3	5.1	3.4	5.1	8.8	3.4	9.4	"
	21-30	4.0	3.0	4.8	4.1	6.1	9.3	4.0	5.4	"
July	1-10	5.3	4.4	6.3	4.4	7.2	13.0	5.1	8.3	"
	11-20	4.3	3.8	5.7	3.7	-	-	4.5	8.0	"

TABLE 4

Diurnal Range on Sunny Days

	A	C	F	H	M	N	S	Mean Sun Hrs
Feb	4.2	3.2	4.5	4.7	7.6	16.5	2.5	7.2
Mar	4.1	3.7	4.5	4.5	8.2	16.8	2.4	8.0
Apr	2.6	2.8	3.3	3.3	6.4	12.1	2.3	11.2
May	3.3	3.2	3.2	3.1	6.1	10.6	3.2	10.9
June	4.7	3.8	6.1	4.4	6.1	10.2	4.6	13.5
July	6.5	5.5	8.1	5.8	8.2	13.2	6.4	12.9

Diurnal Range on Dull Days

	A	C	F	H	M	N	S	Mean Sun Hrs
Feb	1.4	1.1	1.2	1.7	2.4	5.1	0.8	0.3
Mar	1.3	1.2	1.2	1.4	2.2	5.1	1.0	0.0
Apr	0.3	0.5	0,6	0.8	1.5	2.7	0.5	0.2
May	1.1	0.8	1.3	1.1	2.1	4.3	0.5	0.5
June	1.9	1.1	2.3	1.8	3.9	6.6	1.7	0.0

TABLE 5

Regression of Diurnal Range and Sunshine Hours (h)

Period	Range for H		Average Plant Height	
Feb 10-19	1.5 + 0.40h		6 ins	
20-28	1.6 + 0.47h		12 ins	
Mar 1-10	1.3 + 0.51h		18 ins	
11-21	1.5 + 0.47h		24 ins	
22-31	1.6 + 0.27h		3 ft	
April 1-10	1.7 + 0.33h		4 ft	
11-20	2.0 + 0.20h		5 ft	
21-30	1.2 + 0.14h		6 ft	
May 1-10	1.5 + 0.17h		8 ft	
11-21	1.2 + 0.15h		8 ft 6 ins	
22-31	1.1 + 0.15h		Second truss being picked	
Jun 1-10	2.0 + 0.11h	)		
11-20	1.4 + 0.22h	)		
21-30	2.1 + 0.37h	)	Successive	
July 1-10	1.9 + 0.32h	)	picking	
11-20	0.9 + 0.36h	)	of fruit	

Any comments or suggestions on this paper should be referred to the author.

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March 1976